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Principle and Utility of The EUV Laser

The X-ray Laser Plasma Program at the University of Berne

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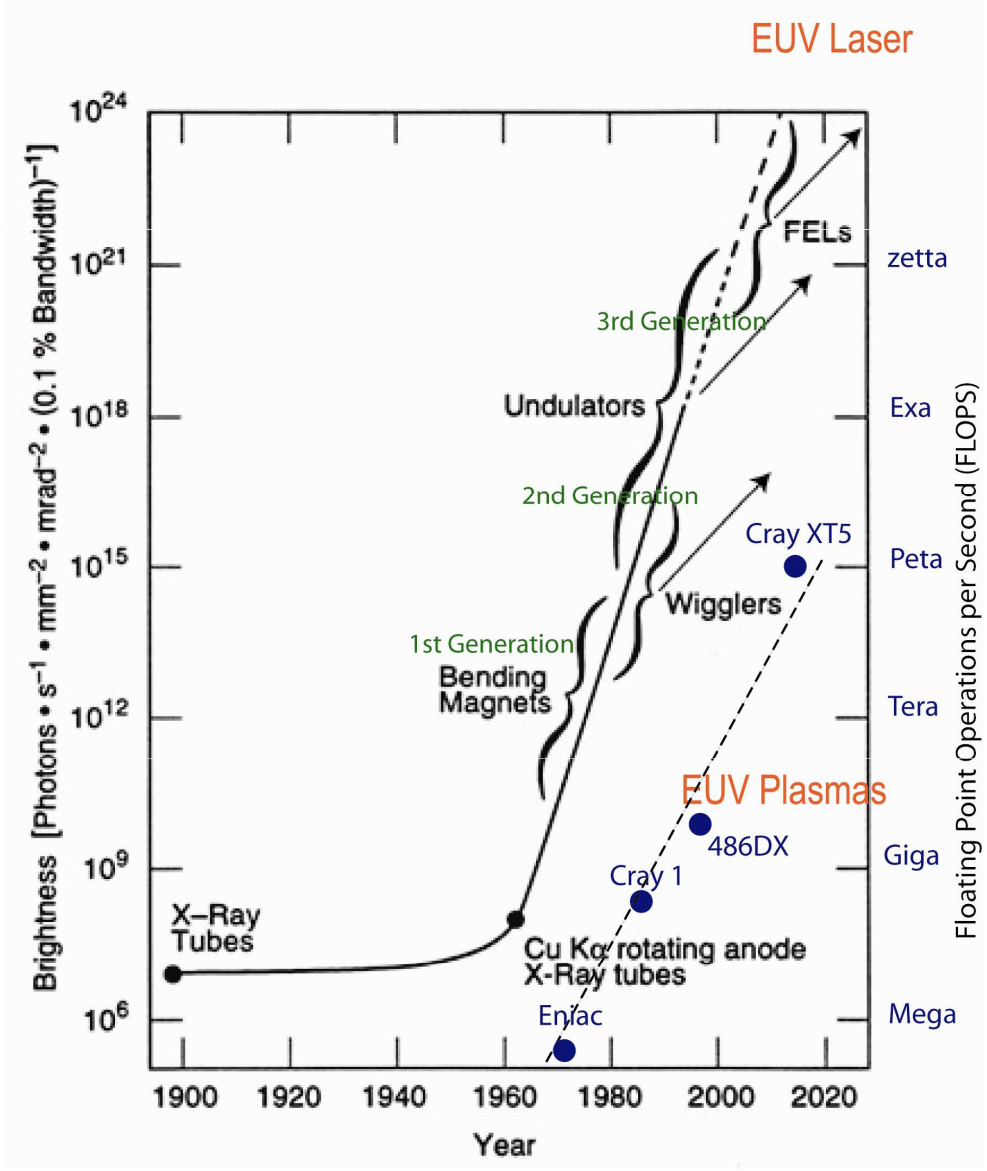
The Quest for EUV Tools
„Light Source Law“ faster than Moore‘s law



„It is an historical fact: scientific revolutions are more often driven by new tools, rather than by new concepts.“

Freeman Dyson, *Theoretical Physicist.*

Modules of the Berne Research Program
Outline of Presentation

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> Fundamentals
- Grazing Incidence Pumping
- Wavefront-tilting
- Pre-pulse Shaping
- Plasma Column Structure

> Instrumentation
- Imaging setup
- Multilayer Optics
- 5Hz XUV Laser
- Pixel-free Detection

> Imaging
- All-reflective Design
- (Fresnel Zone Plate Imaging)

> Spectroscopy
- Photo-electron at hν = 100eV
- Angle Resolved - PES

Principle of EUV Laser
Travelling ASE across a Plasma Column

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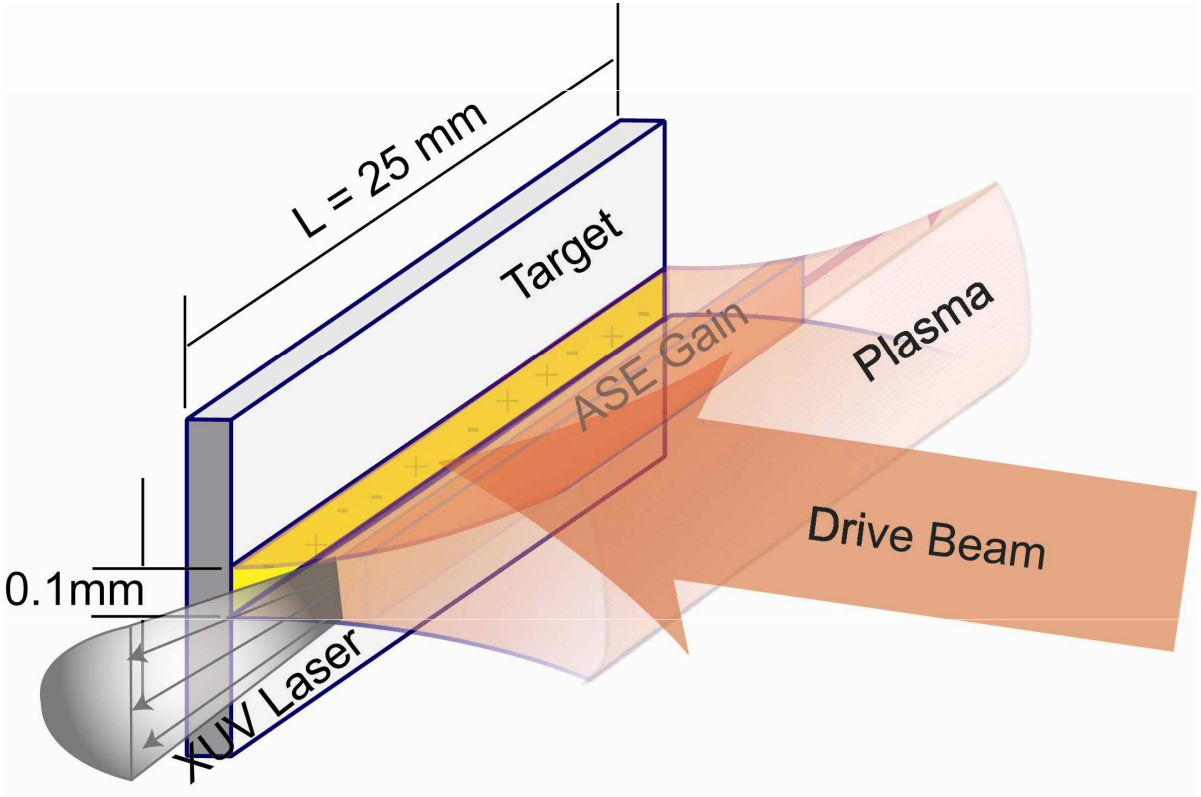
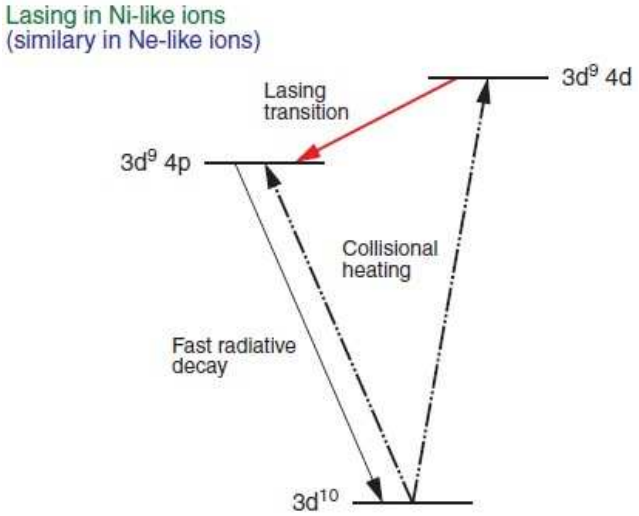
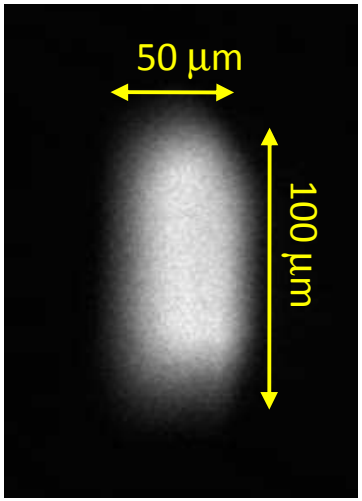
ASE = Amplified Spontaneous Emission







EUV Laser Facility

Single shot source operational
A 5Hz source under construction

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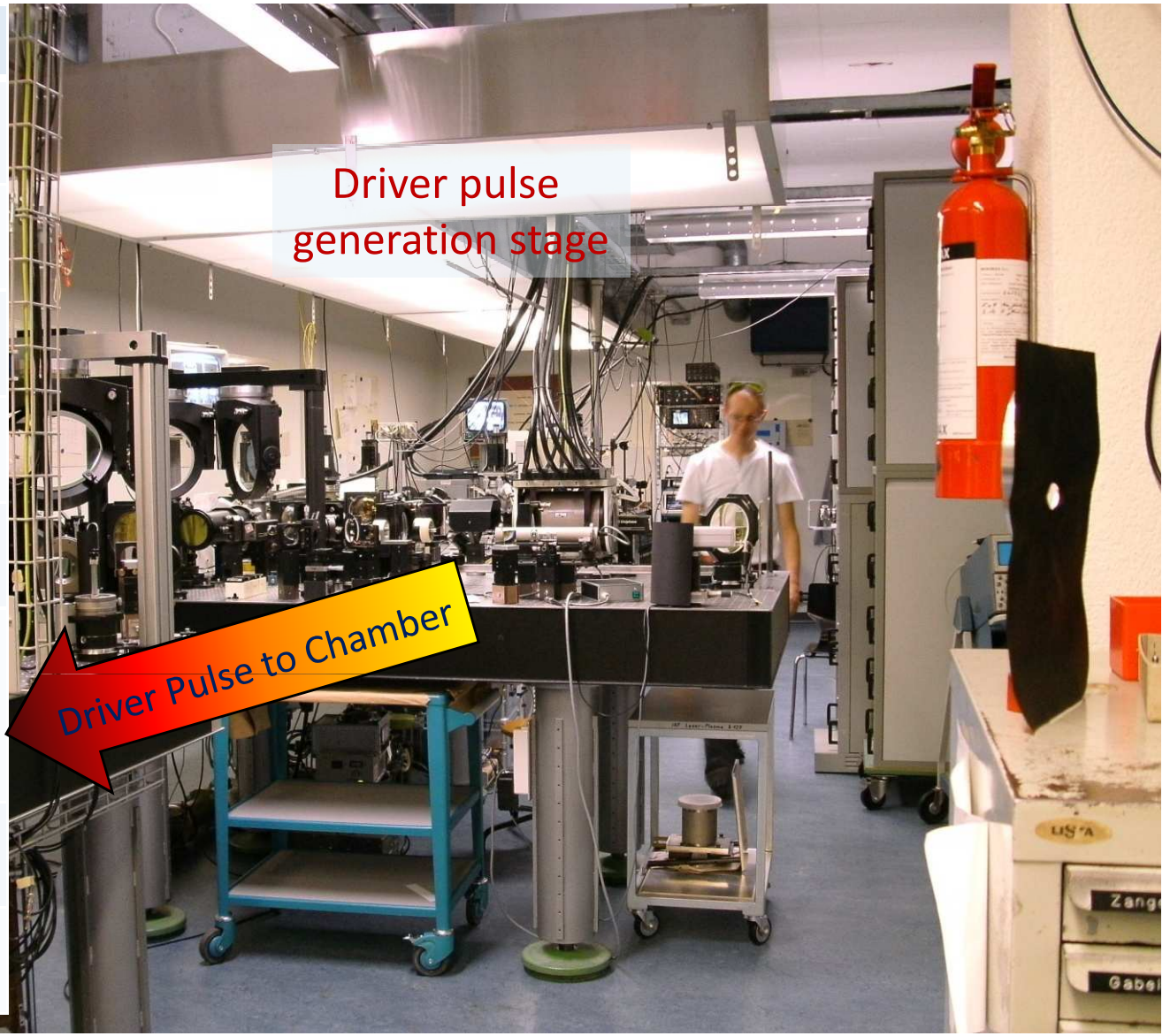
Specifications	Driver	XUV Laser
Energy [J]	1 - 20	~5µJ
Pulse [ps]	1.3	~5
Power [W]	>10^{12}	~10^{6}
Intensity [W/cm^2]	>10^{13}	~10^{10}
Fluence [mJ/cm^2]	~10^{6}	up to 500
Brightness [ph s-1 mm-2 mrad-1 0.1%BW]		>10^{25}
Wavelength [nm]		Soft X-ray / EUV
Bandwidth [$\Delta\lambda/\lambda$]		~6 10^{-5}



The Quest for EUV Tools
Brightness for Quality, Power for Quantity

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Source Typology		Incoherent (LPP)	Coherent (XRL)
Driver Energy		0.2J	3.5J
Conversion Efficiency		2.5%	1.5 10^{-6}
Wavelength (Sn)		13.5nm	12.0nm
Rep. rate		1.2kHz	Single shot
EUV Power	>Pulse >CW (1s)	0.1MW 6W	1.5 MW **5μW**
Bandwidth [$\Delta\lambda/\lambda$]		2%	<0.001%
Emittance		10^{+7} mrad^2 (=4π sr.)	8 mrad^2 (=2 x 4mrad)
Brightness [ph. units]	>Pulse >CW	10^{+14} 10^{+10}	**>10^{+25}** 10^{+14}

$$L = \frac{\mathrm{d}^2\Phi}{\mathrm{d}A\,\mathrm{d}\Omega\cos\theta} \approx \frac{\Phi}{\Omega A\cos\theta}$$

HVM

Actinic Metrology

EUV Laser Emission Lines
Discrete Tunability by Target Selection

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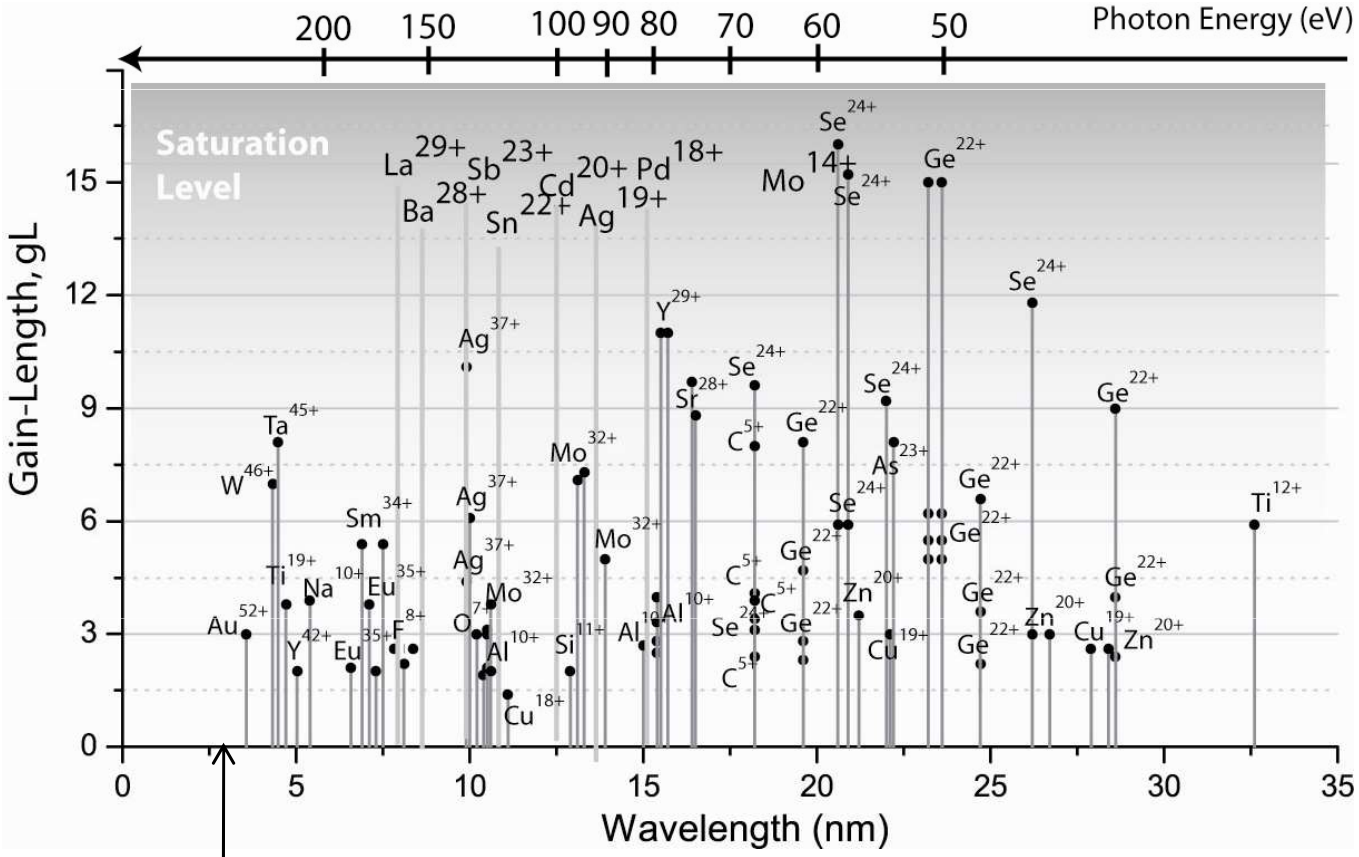
XRL Lines Saturated in Our Lab:

XRL Target	λ (nm)	E(eV)
Pd	14.7	84.3
Ag	13.9	89.2
Cd	13.2	93.9
Sn	12.0	103.3
Sb	11.4	108.2
Ba	9.2	134.8
La	8.9	139.3
Sm	7.3, 6.9	169.8, 179.7

EUV-L

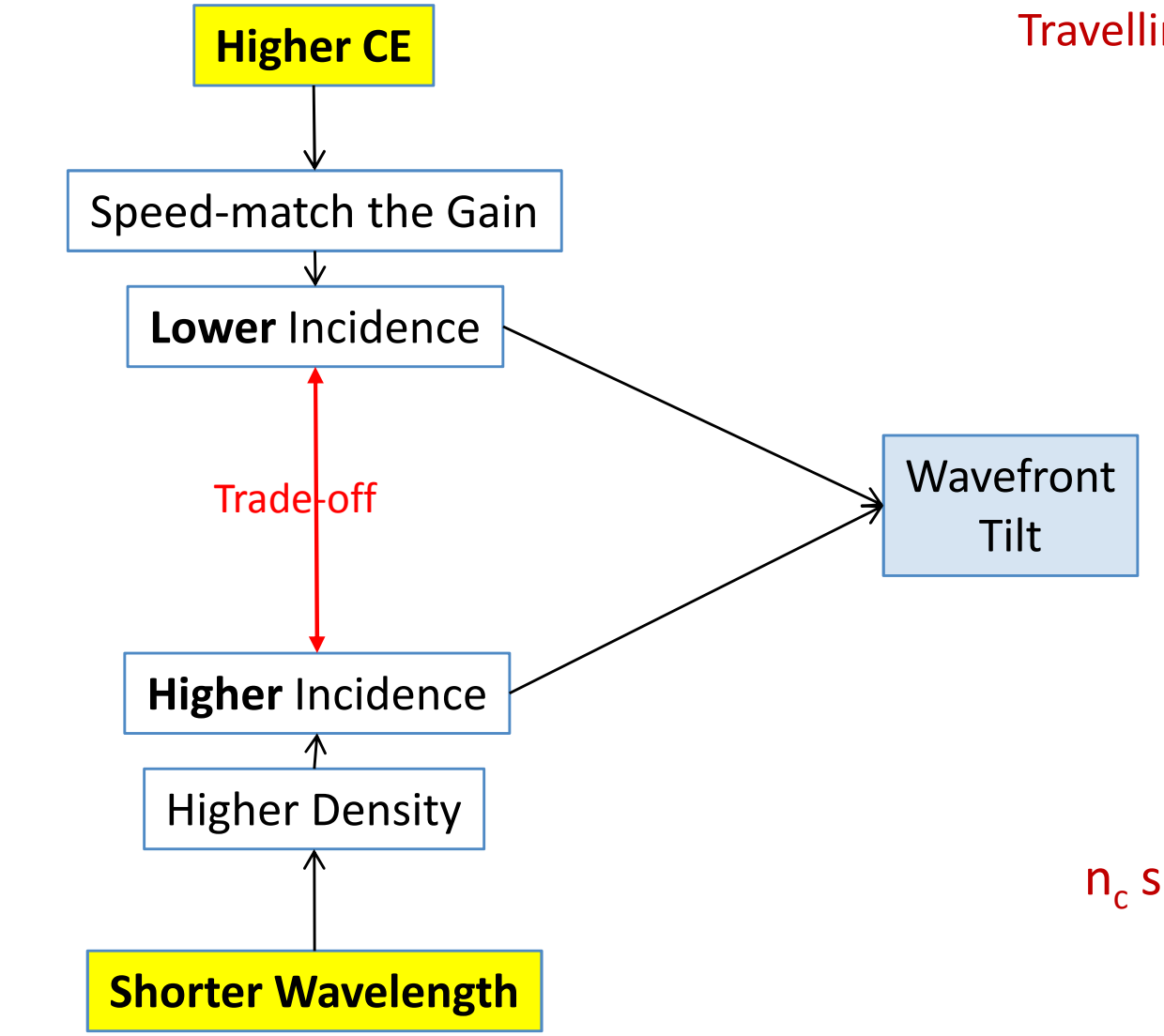


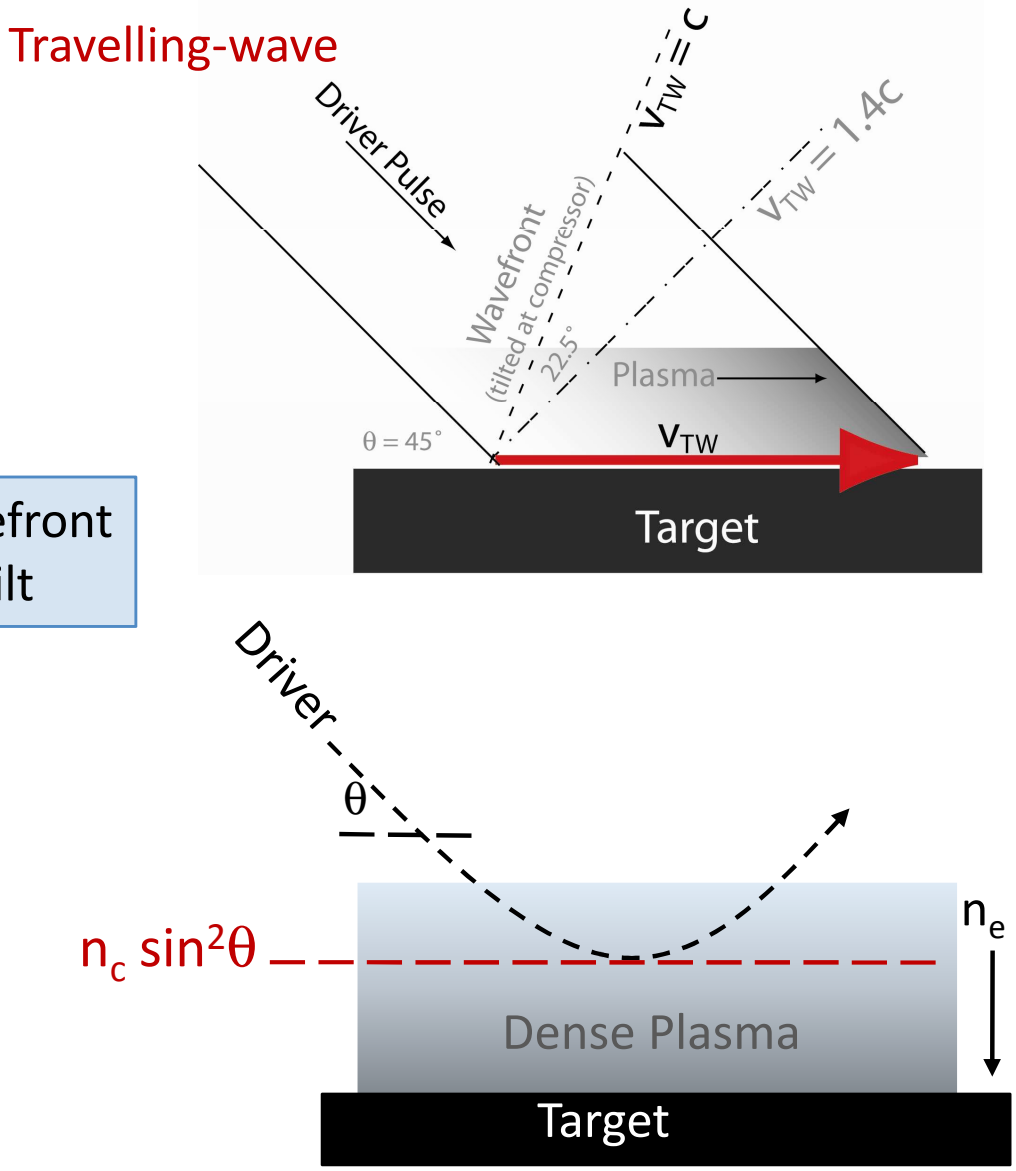
Bio-Imaging

Needs more efficient pumping → **Higher CE**

Travelling-Wave Pumping Improved

Wavefront tilt overcomes trade-off CE vs. short λ_{XRL}





Grazing Incidence Pumping
Prepulses & GRIP improve the conversion efficiency

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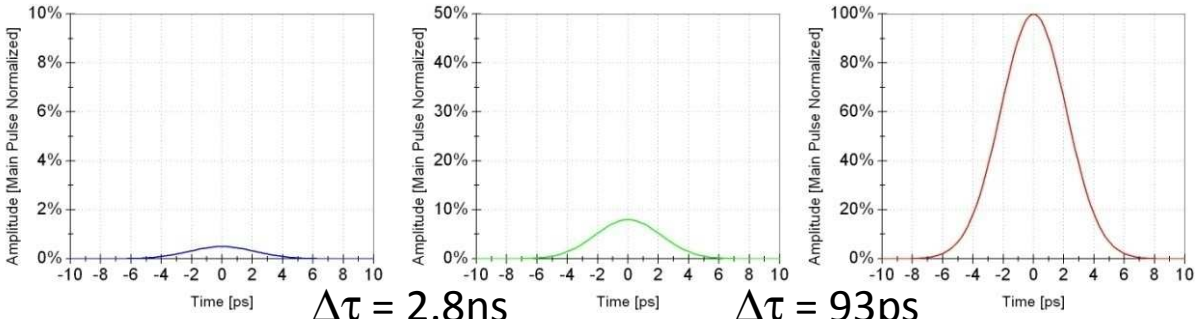
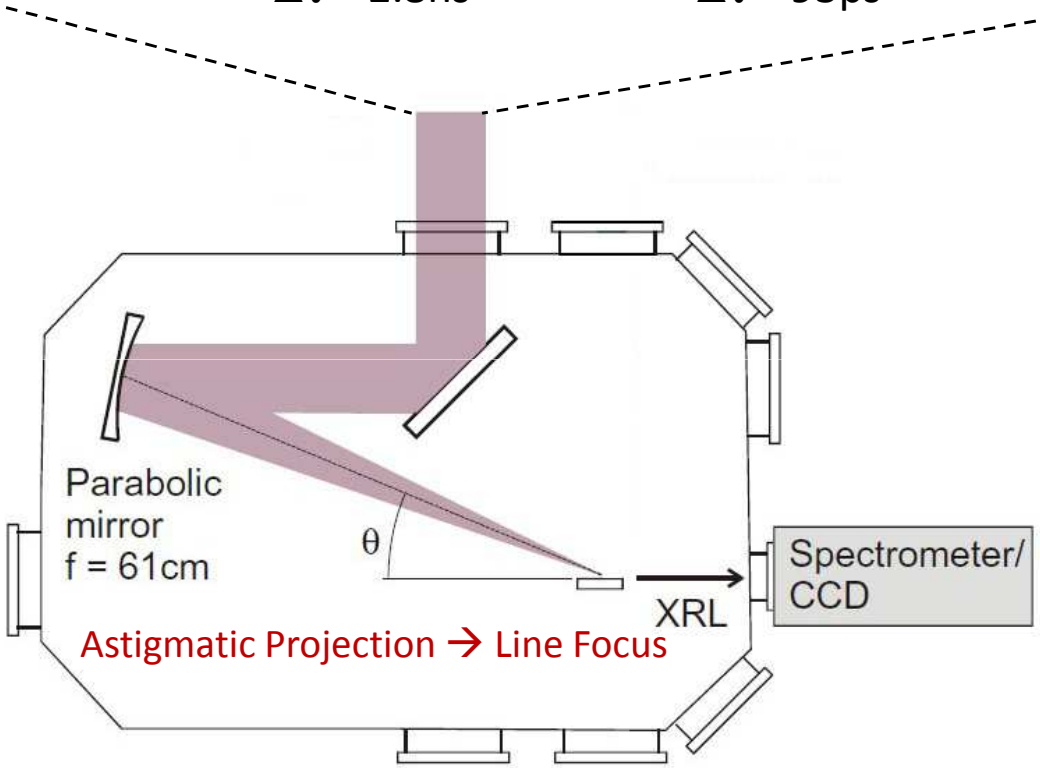
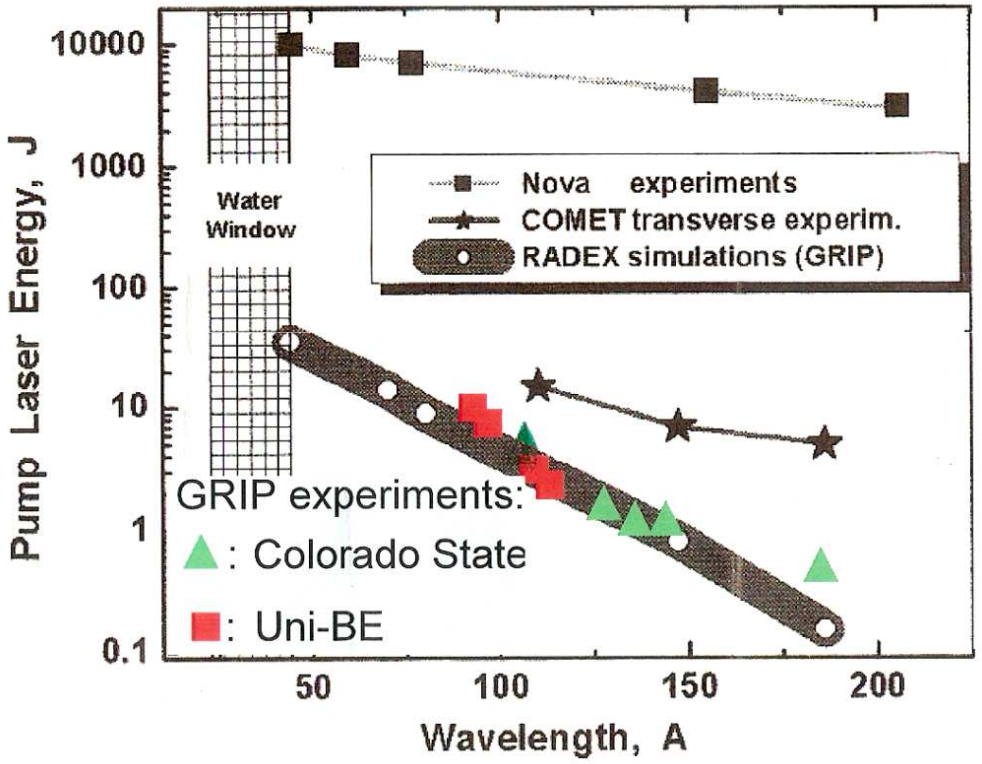
0.5% Pre-pulse | 8% Pre-pulse | Main pulse

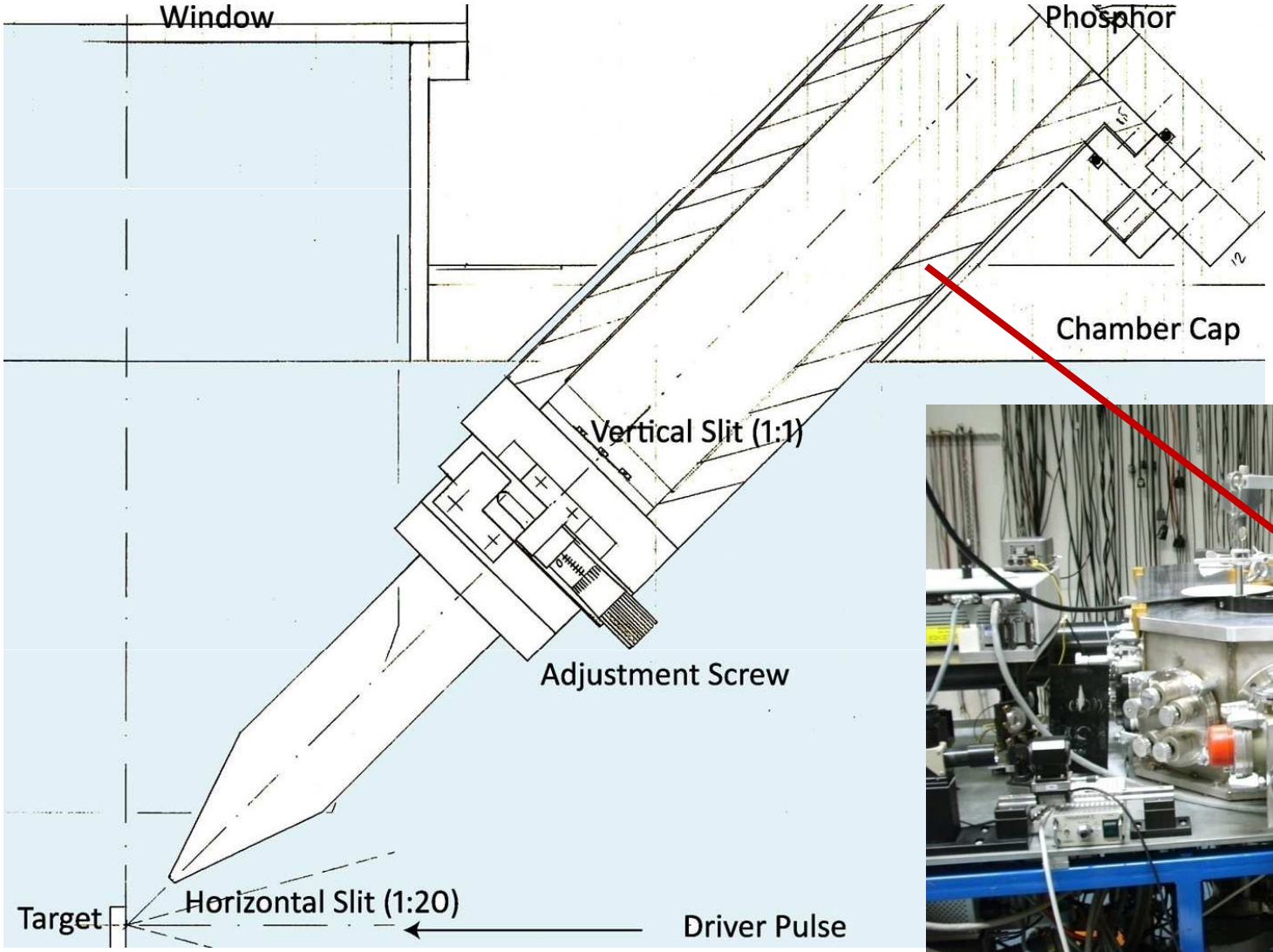


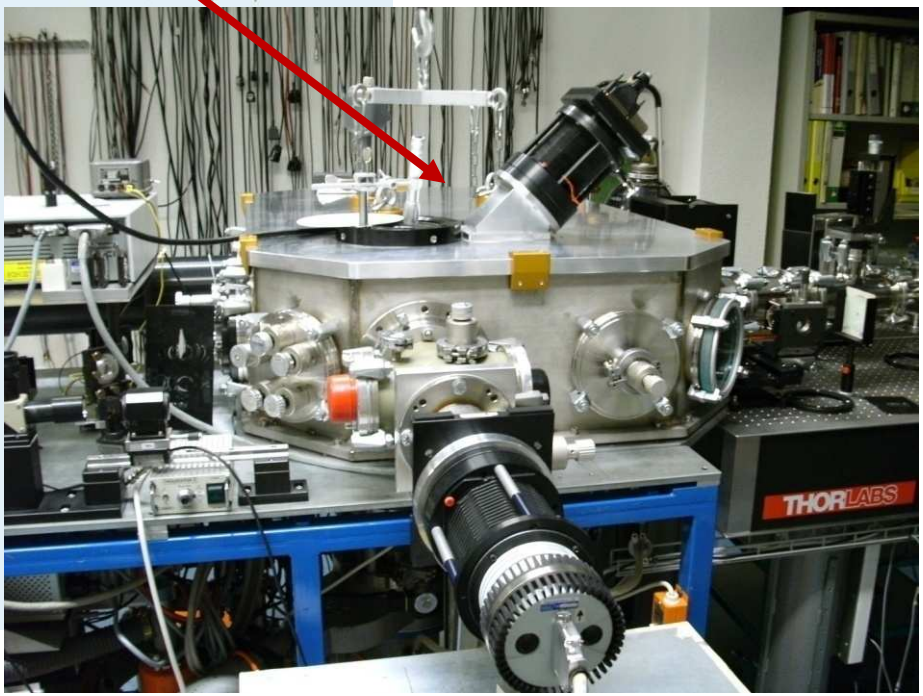


M. Grünig et al. OPT COMM. 282, 267-271, 2009



Plasma Column Homogeneity
Pinhole Camera Measurement of Plasma Length





Plasma Imaging
Gain Column Modulation Observed

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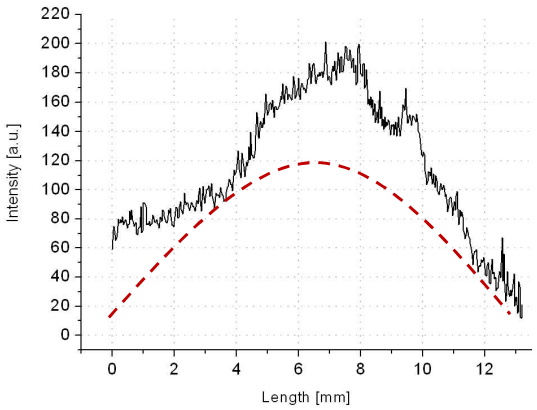
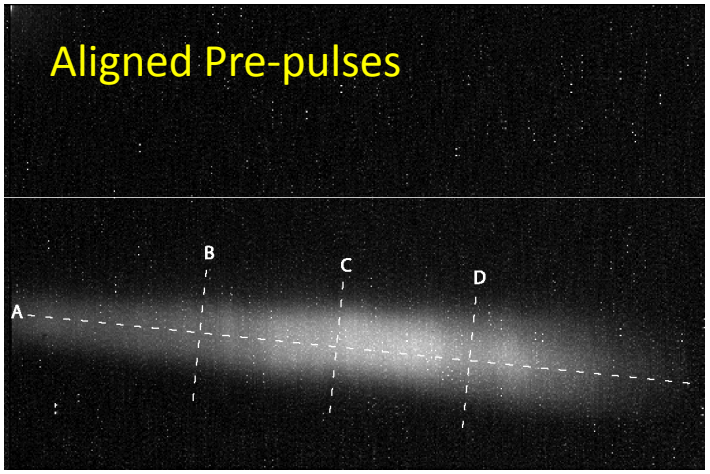
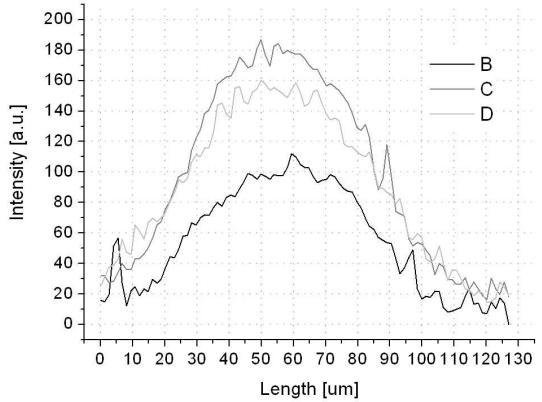
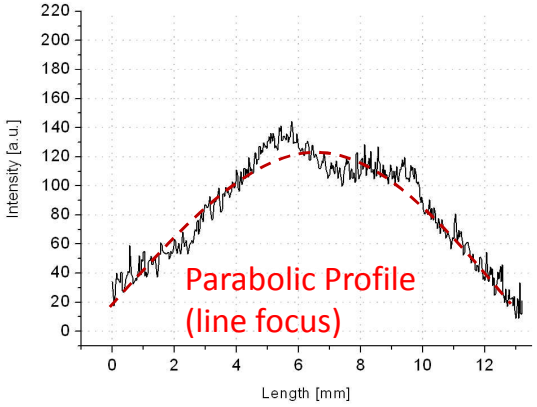
Longitudinal Profile ("A")

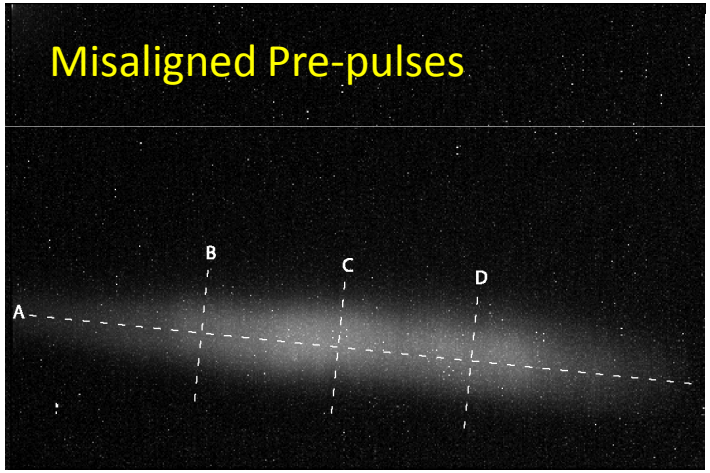


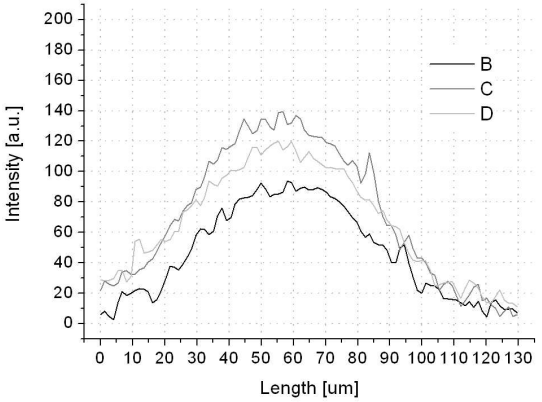


Cross-Sections ("B","C","D")

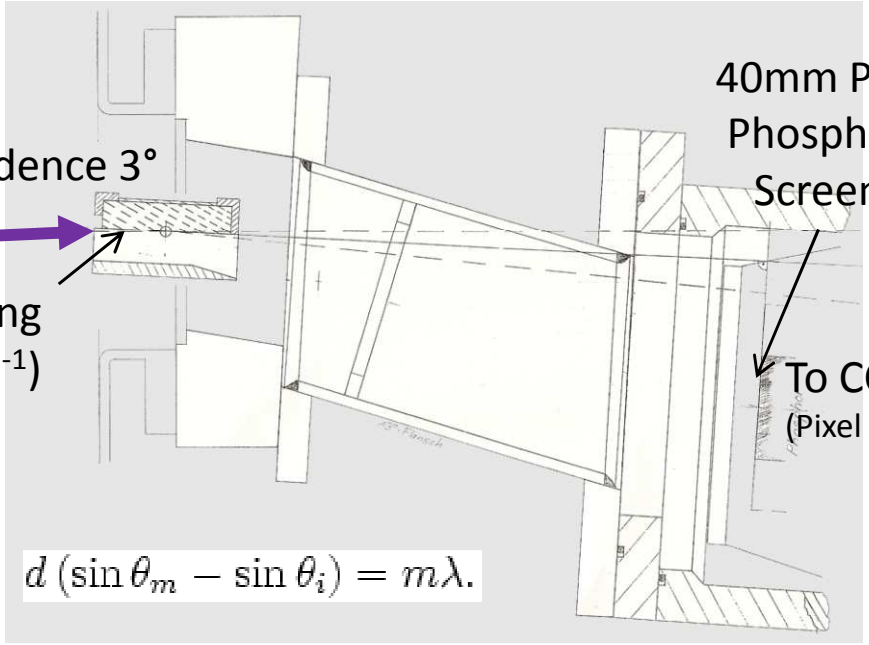


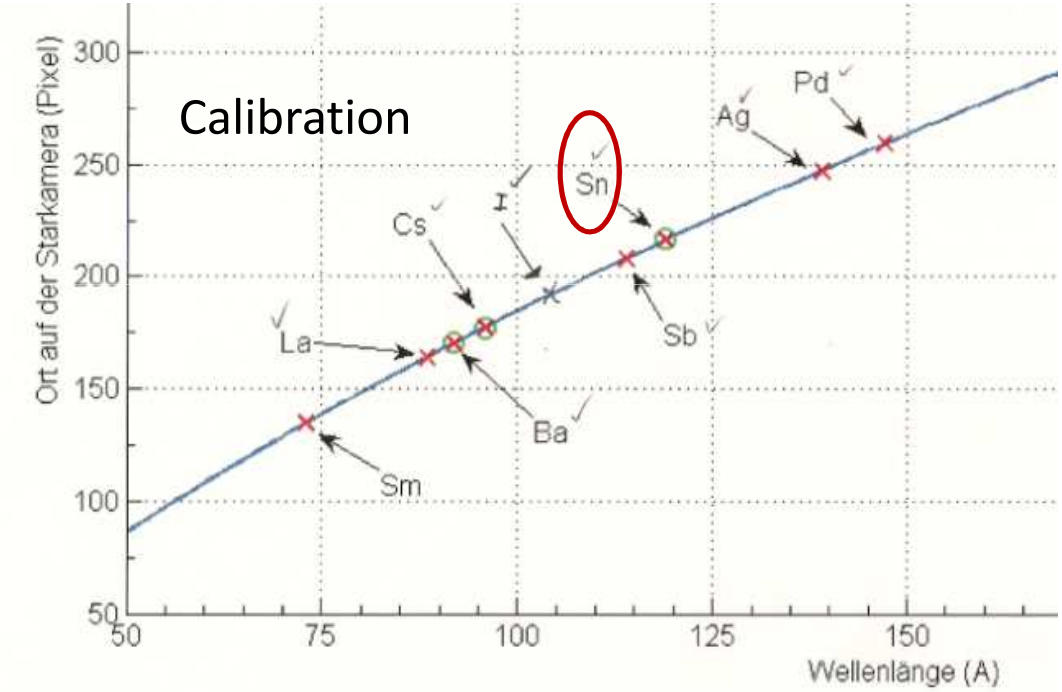


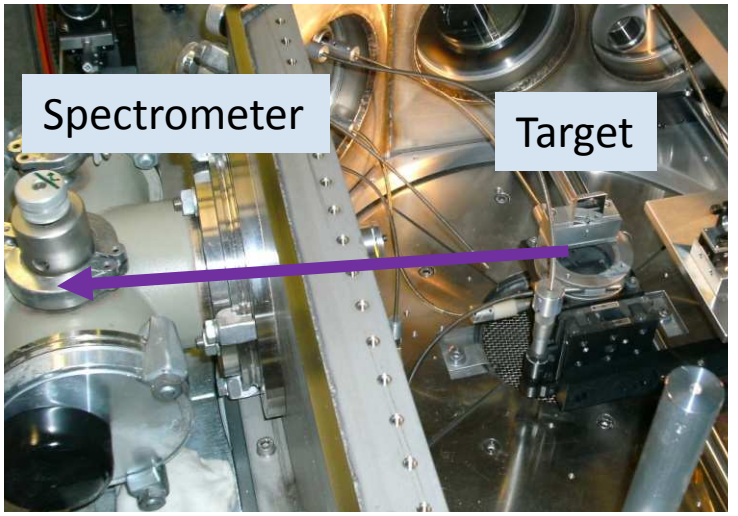




Grating Spectrometer
Measurement of Linewidth and Divergence







Sn EUV Laser Spectral Characteristics
High Spectral Cleanliness

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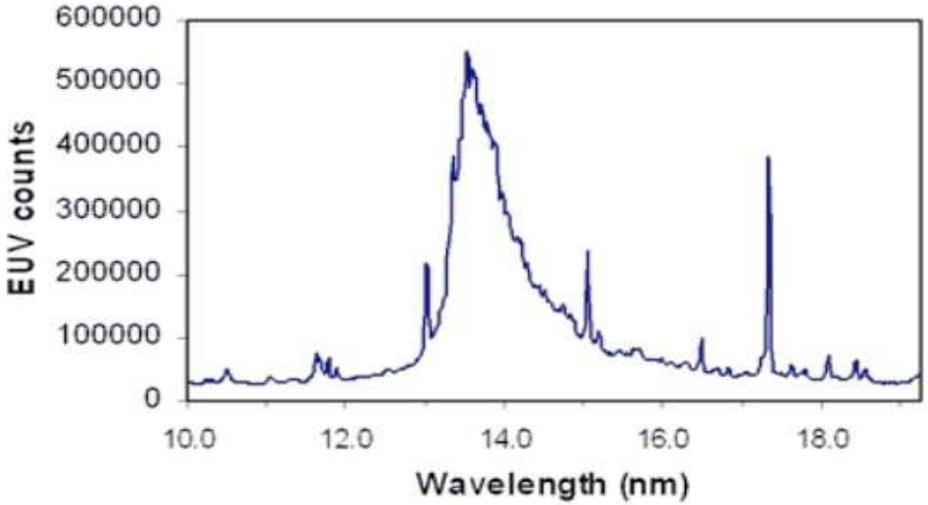
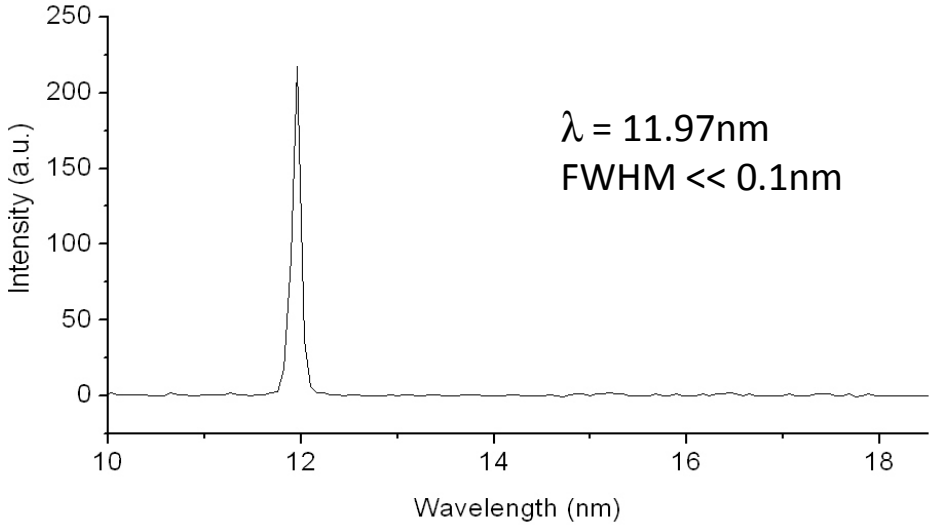
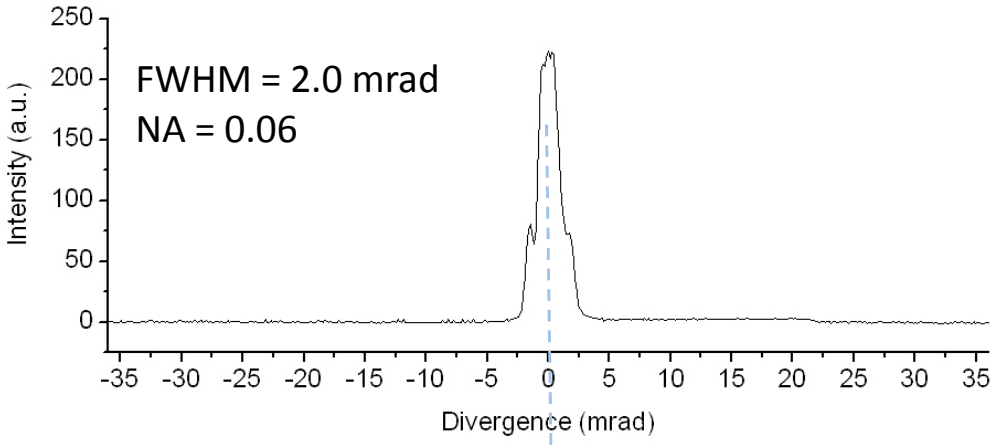
For comparison LPP emission with mass-limited Sn target (CREOL UCF)

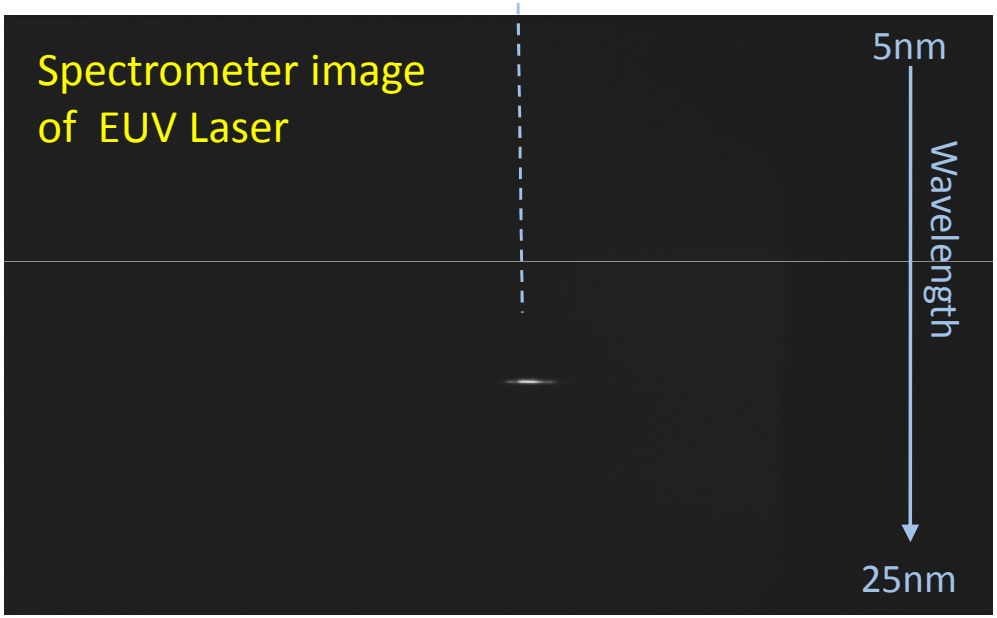




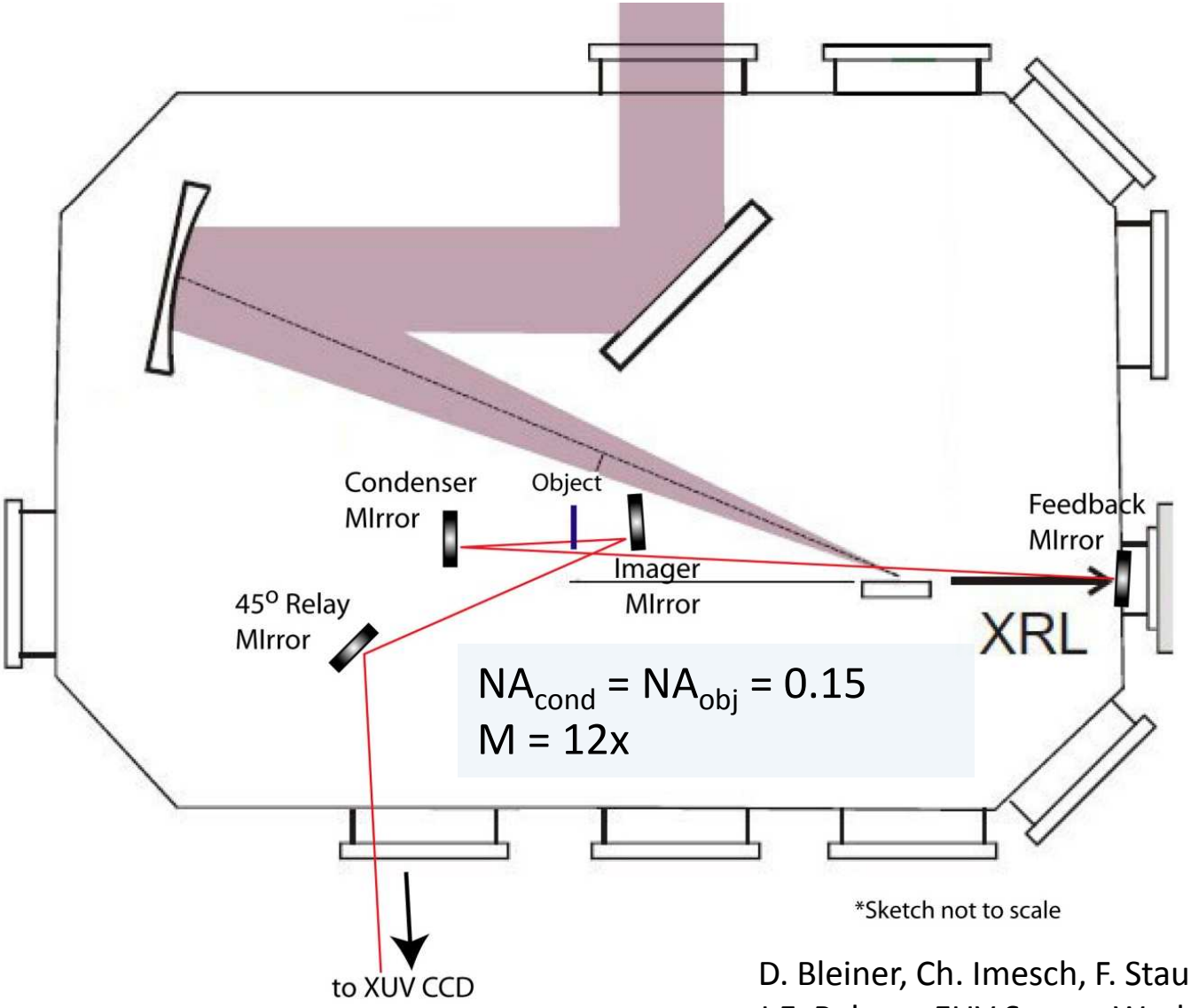
λ = 11.97nm
FWHM << 0.1nm



FWHM = 2.0 mrad
NA = 0.06

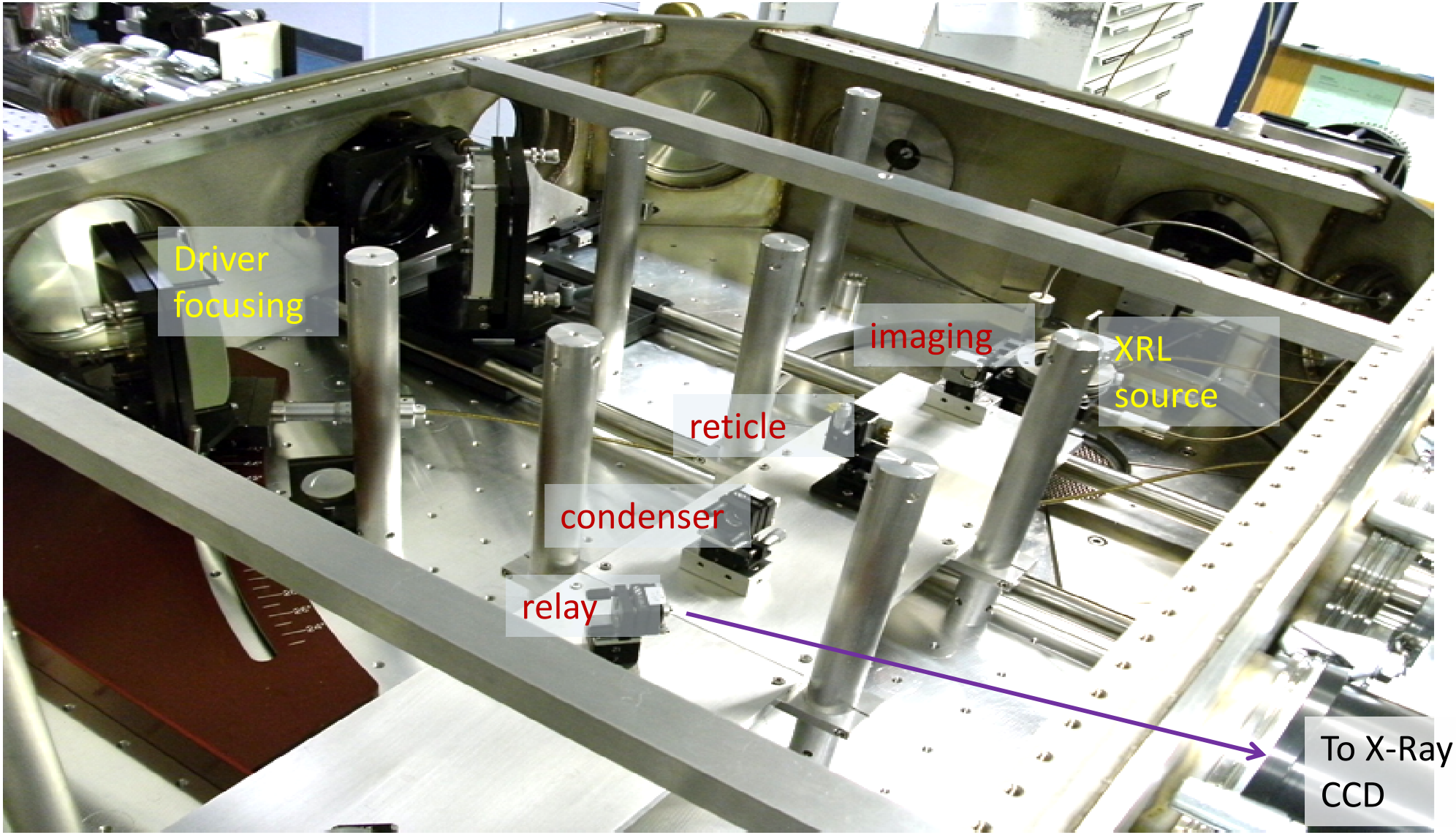


Experimental Setup of the EUV Imaging
Raytracing Optimization Presented in Maui



D. Bleiner, Ch. Imesch, F. Staub, Y. Ekinci, V. Bakshi, J.E. Balmer, EUV Source Workshop 2010, Maui.

Experimental Setup of the EUV Imaging



Multilayer Optics in the All-Reflex Setup

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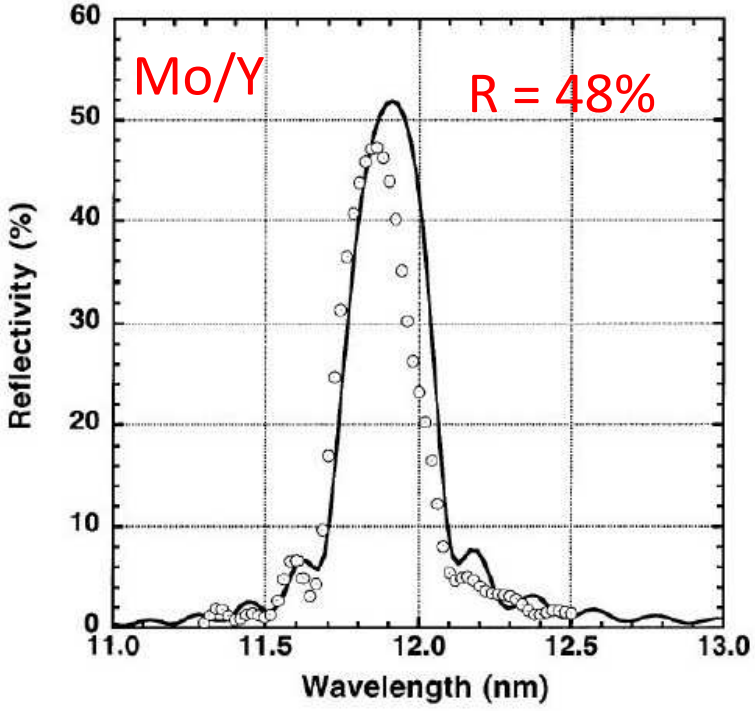
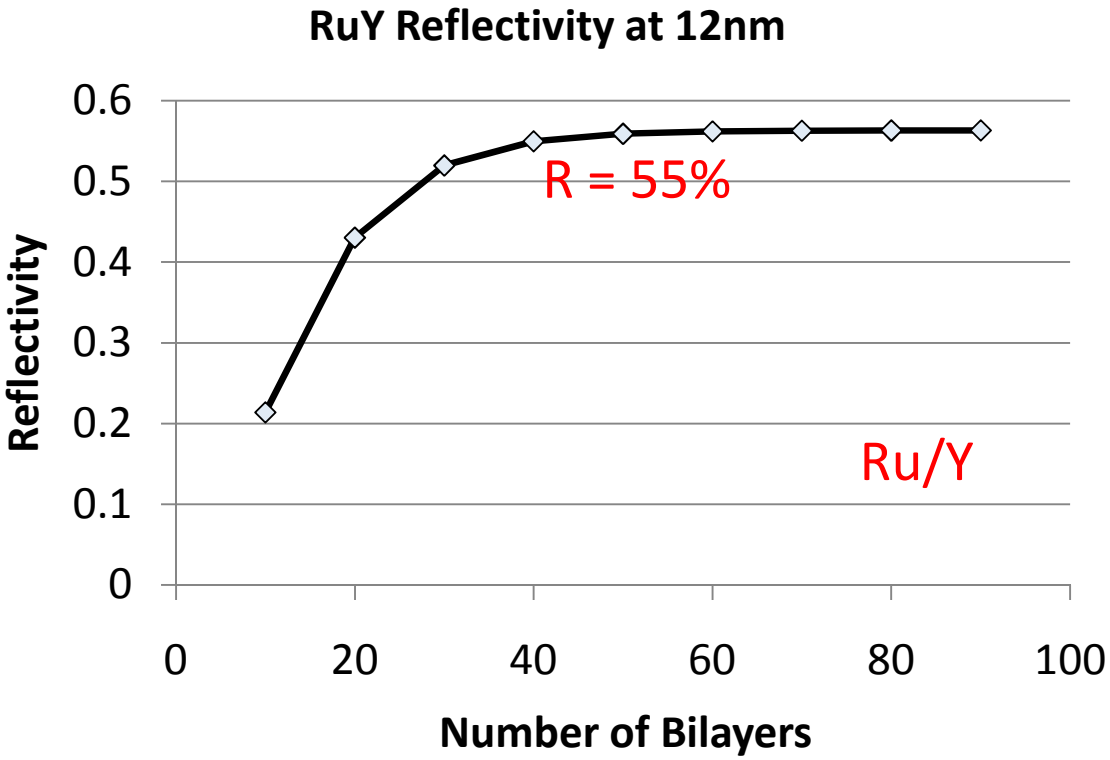
Imaging Optics Radius of Curvature	Pixel Resolution
240.7mm	**950nm**
Schwarzschild	90nm

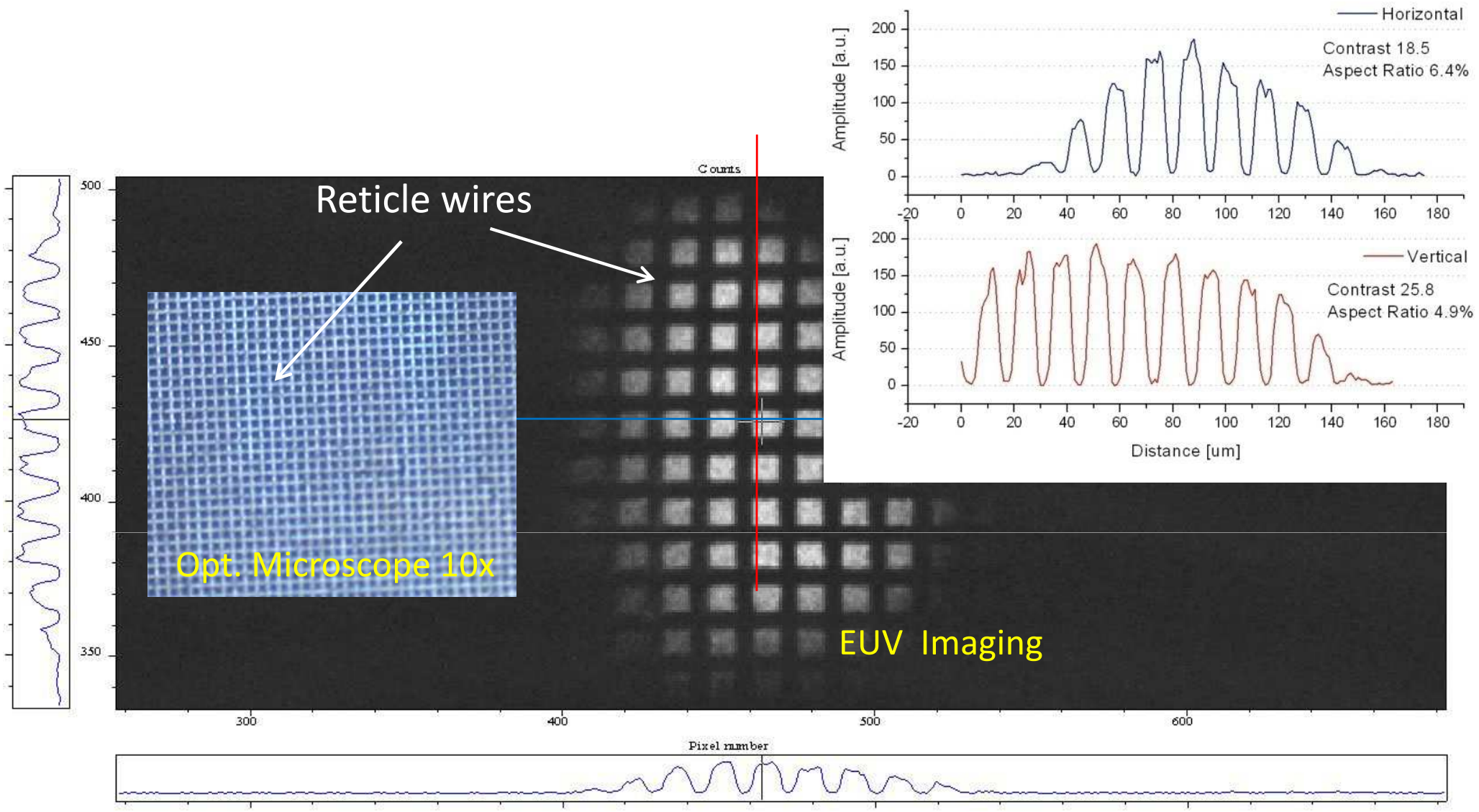
J. Nilsen, S. Bajt, H. N. Chapman, F. Staub, J.Balmer, OPT. LETT. 28, 2249-2251, 2003.



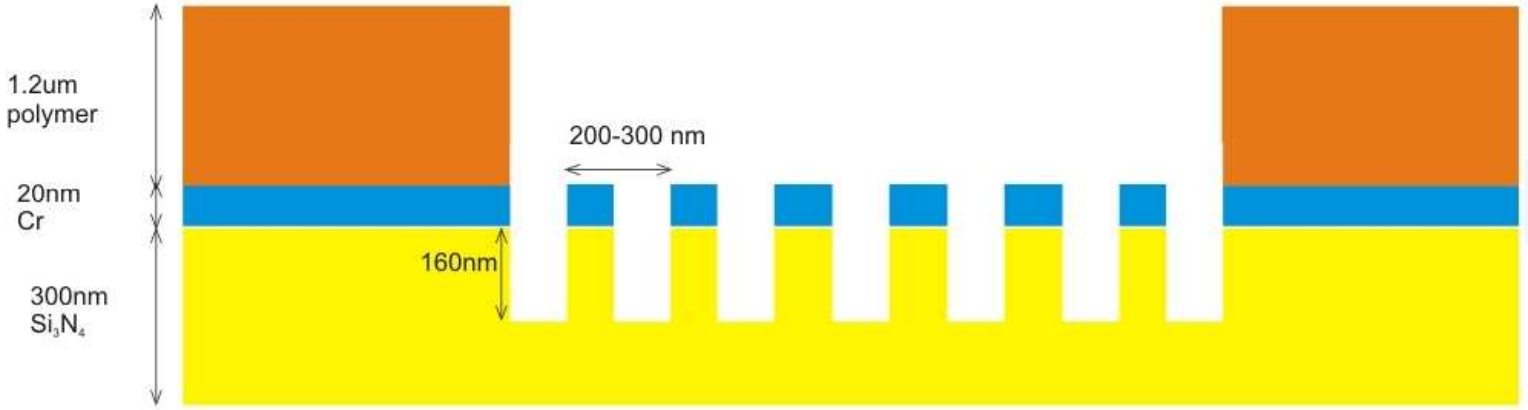


Transmission Imaging Through a Reticle

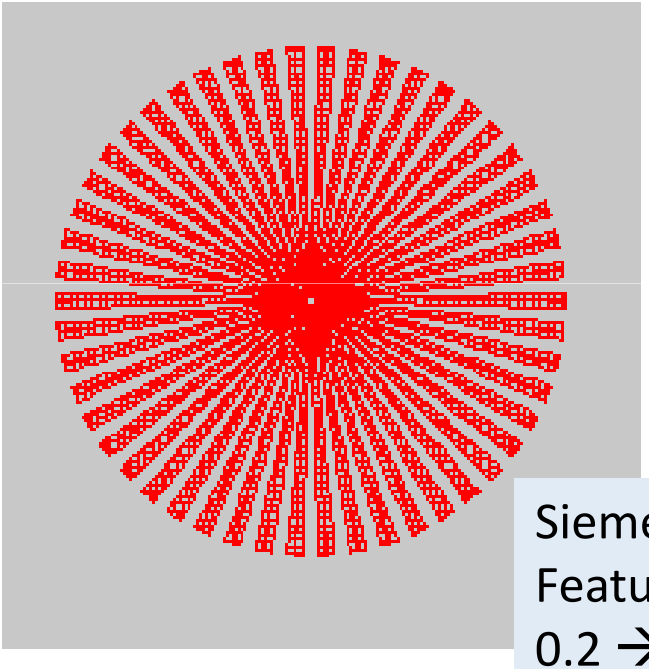
First results of EUV Microscope



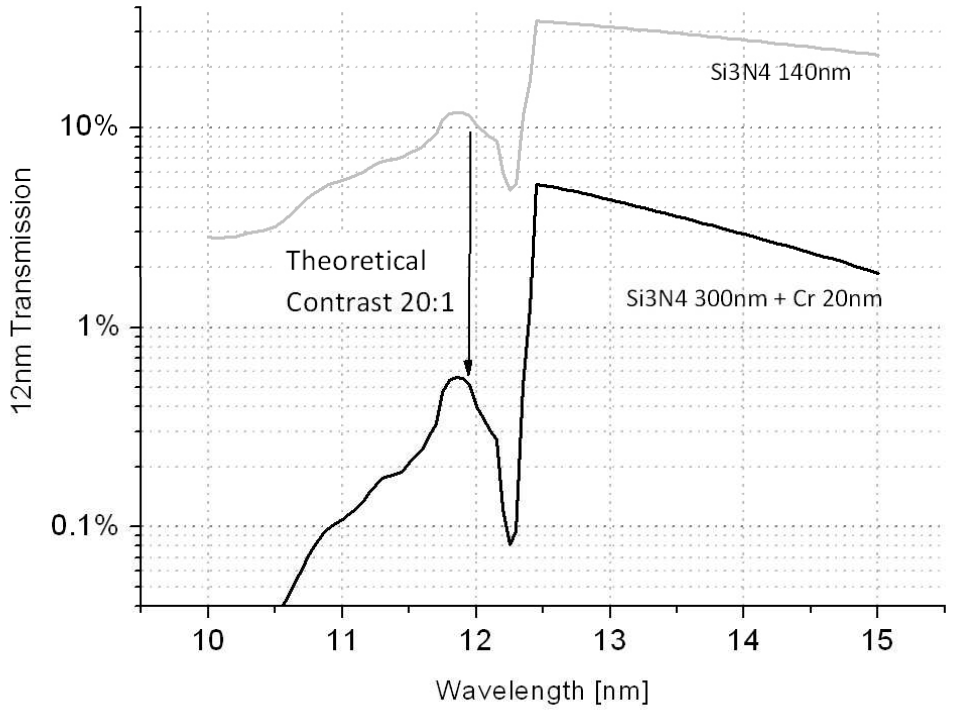
Reference Sample Exposed
Absorber thickness to be further adjusted



Absorber

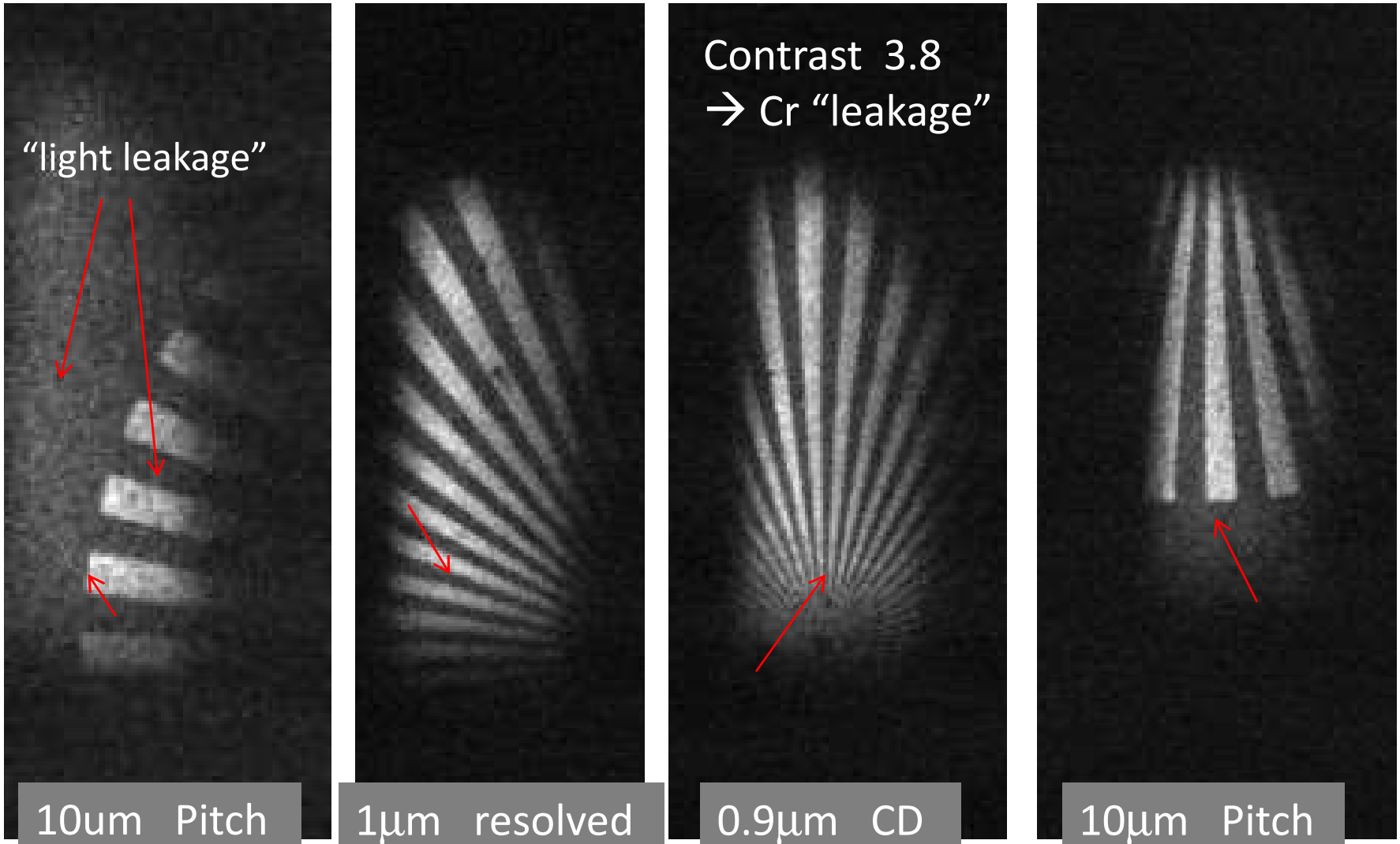


Siemens Star's
Features:
0.2 → 10 µm



Siemens Star Imaging at 12nm EUV

Identical characteristics in vertical and horizontal



Summary
Principle and Utility of The EUV Laser

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- University of Berne's Facilities:
  - Single Shot EUV Laser Facility operational.
  - 5Hz System underway.
- Compared to LPP:
  - "Brightness for High Quality, Power for High Quantity in EUV Lithography."
- XRL Principle:
  - Amplification across a Laser Plasma Column Leads to Coherent XUV Photons.
  - Wavefront tilt GRIP improves CE and gives access to short wavelengths.
  - Plasma structure was visualized.
  - High spectral cleanliness demonstrated.
- XRL Utility:
  - Debris-free and collector-less source.
  - First results of an all-reflective imaging setup.
  - Plans for Schwarzschild optics.

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  - V. Bakshi
- Paul Scherrer Institute:
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- University of Berne:
  - Th. Feurer, B. Locher